Experiment – 07

Impact of Interference in 5G Networks

Objective

In this experiment, we will simulate and study the impact of downlink interference on the signal-to-interference ratio (SINR) in Netsim **v13.3**. We will study the following aspects.

A. We consider a handover procedure in a cellular system and analyse the following cases:
   1. The handover of a UE without any interference, with pathloss exponent, $\eta = 2.5$,
   2. The handover of a UE without any interference, with pathloss exponent $\eta = 4$,
   3. The handover of a UE with interference, with pathloss exponent $\eta = 2.5$, and
   4. The handover of a UE with interference, with pathloss exponent $\eta = 4$.

B. To understand the effect of path loss exponents with and without interferences on the point of handovers in cellular systems.

In this experiment, we consider the following handover scenario: A UE starts from BS_1 and moves in a straight line to BS_2. While the UE is attached to BS_1 it experiences interference from BS_2. Once it gets handed over to BS_2 the UE experiences interference from BS_1. There is always thus only one interferer, and we analyse the SINR as the UE moves a straight line from BS_1 to BS_2.

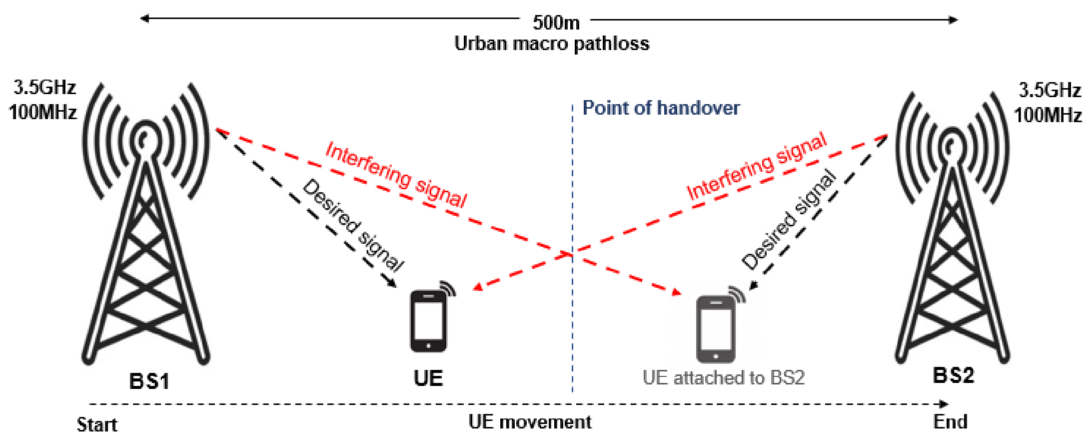


Fig 1: UE1 is initially attached to BS1. The signal from BS1 is the desired signal while the signal from BS2 is the interfering signal. Post-handover, the desired signal is transmitted from BS2 while signal from BS1 is the interfering signal. We assume omni-directional antennas at both BSs and consider cases with $\eta = 2.5, 4$.

Introduction[1]

Due to the scarcity of the wireless spectrum, it is not possible in 5G networks to separate concurrent transmissions completely in frequency. Some transmissions will necessarily occur

[1] Some of the content in this section is from [1].

at the same time in the same frequency band, separated only in space, and the signals operating on the same time-frequency resources from many undesired or interfering transmitters are added to the desired transmitter's signal at a receiver. The main determinants of the interference are

- The network geometry, i.e., the location of the receivers and the transmitters
- Base stations' (or gNBs') transmit power, and
- The path loss model (signal attenuation with distance).

The performance and coverage of a 5G network critically depends on the signal-to-interference-and-noise ratios (SINRs) level at the receivers. This is defined as

$$SINR = \frac{P_r}{N_0 W + I}$$

Where P_r is the received power of the desired signal, W is the bandwidth, $N_0 W$ is the thermal noise and I is the received power of interfering signals. In 5G, the modulation and coding scheme (MCS) is computed from the SINR. The higher the SINR, the higher the MCS, and hence the higher the date rate. Interference is therefore an important performance-limiting factor in wireless networks and hence it is crucial to characterize the effect of interference.

A. Network setup: ISD = 500m, C Band, 100 MHz, Urban Macro.

In our network scenario, the inter-site distance (ISD) between BS_1 and BS_2 is 500m. Both base stations (gNB) operate in the 3.5 GHz band, called the C band, with a bandwidth of 100 MHz. The environment is assumed to be urban with signal attenuation as per the 3G PP Urban Macro pathloss model. Shadow-fading and fast fading are turned off to avoid sources of randomness.

Case #1: No interference in both base stations with $\boldsymbol{\eta = 2.5}$

Procedure:

1. Open Netsim v13.3 available on the desktop.
2. The first task is to create a new workspace.
3. On the ***"Your Work"*** window, select **'Workspaces'**, and click on "**List of Workspaces**" as shown in Fig 2
4. Then click on "**New Workspace**" and name your workspace and **locate to your own folder** Fig 3

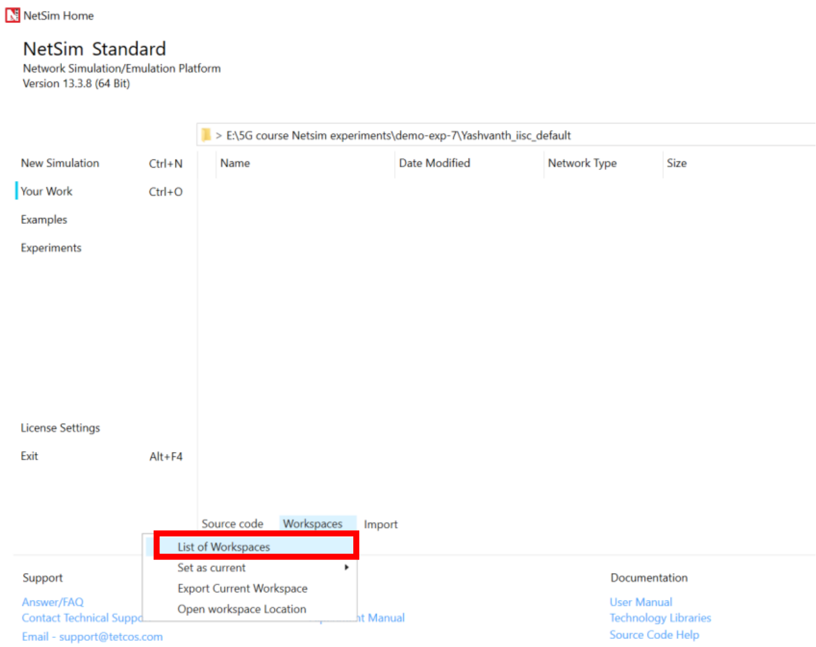


Fig 2: Your Work Page of Netsim.

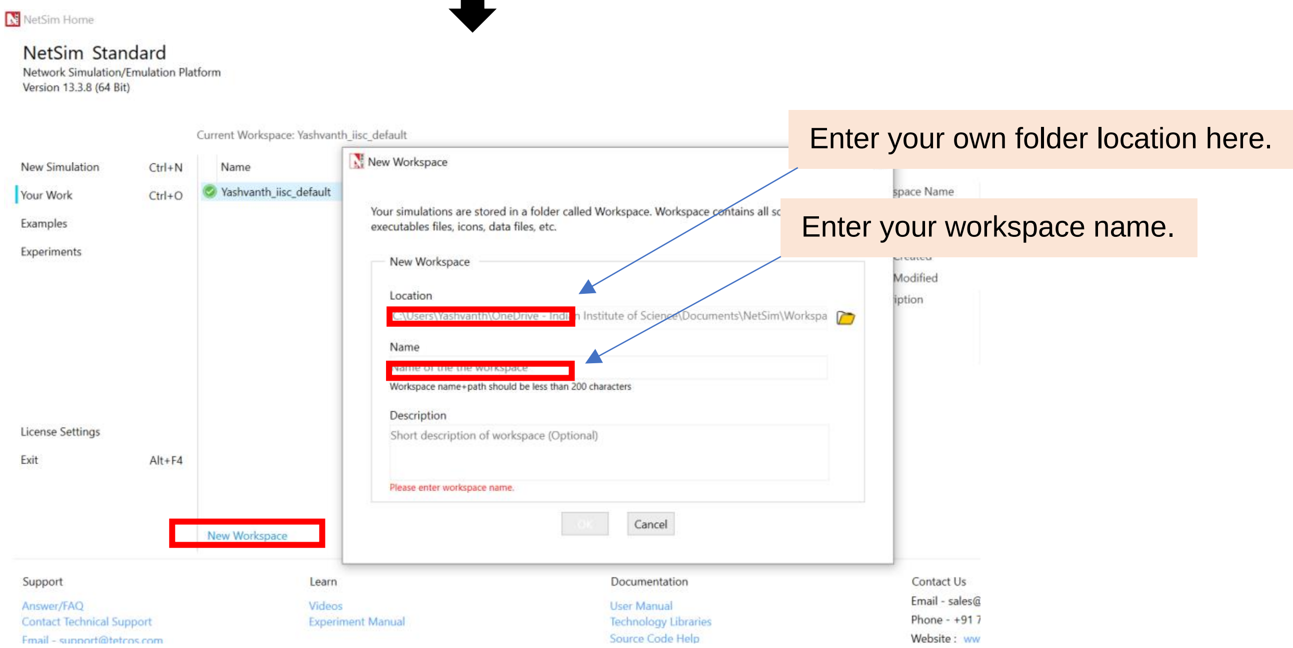


Fig 3: Creating a new Workspace.

5. Use the following download Link to download the netsim workspace file (*.netsimexp). for experiment – 7 only: [Exp_7_Impact_of_interference_in_5G.netsimexp]
6. Go to NetSim Home window, go to Your Work and click on Import.
7. In the Import Workspace Window, browse and select the *.netsimexp file from the extracted directory. See Fig 4

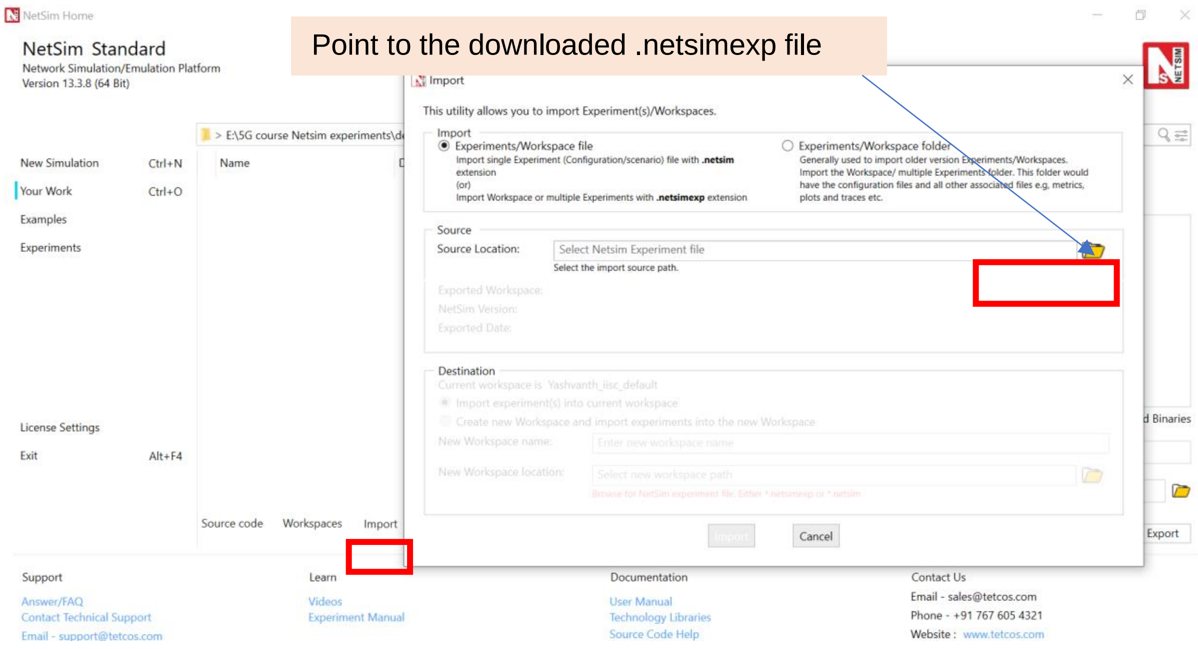


Fig 4: Loading the workspace.

8. The configuration files for the four scenarios of this experiment will appear on the screen, click on the first case and perform the experiment.

Network Scenario

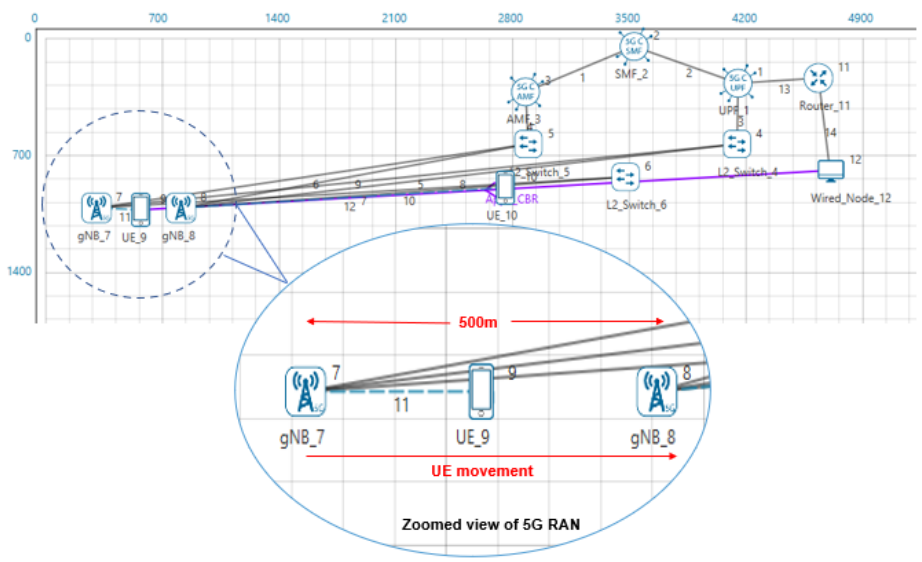


Fig 5: NetSim Scenario during mobility.

Simulation parameters:

Consider the grid environment as 700 m. Place the two gNBs on the grid environment. Distance between two gNBs is 500m.

Devices	X	Y
gNB_8	800	200
gNB_7	300	200

UE_9	300	200
UE_10	300	760

Table 1:Device Co-ordinates

9. Go to gNB properties. In the RAN interface set physical layer properties as shown in the below table. Similarly set the same properties in another gNB.

gnb> Interface 5G RAN	
gNB Height (m)	10
Tx Power (dBm)	40dBm
Tx Antenna Count	1
Rx Antenna Count	1
CA Type	Single Band
CA Configuration	n78 (C Band)
F_Low (MHz)	3300
F_High (MHz)	3800
DL: UL Ratio	4:1
Numerology	2
Channel Bandwidth (MHz)	100MHZ
MCS Table	QAM64
CQI Table	TABLE1
Outdoor Scenario	Urban Macro
Indoor Office Type	Mixed Office
PathLoss Model	LOG_DISTANCE
PathLoss Exponent	2.5
Shadow Fading Model	None
Fading and Beamforming	NO FADING MIMO UNIT GAIN
Downlink interference model	No interference

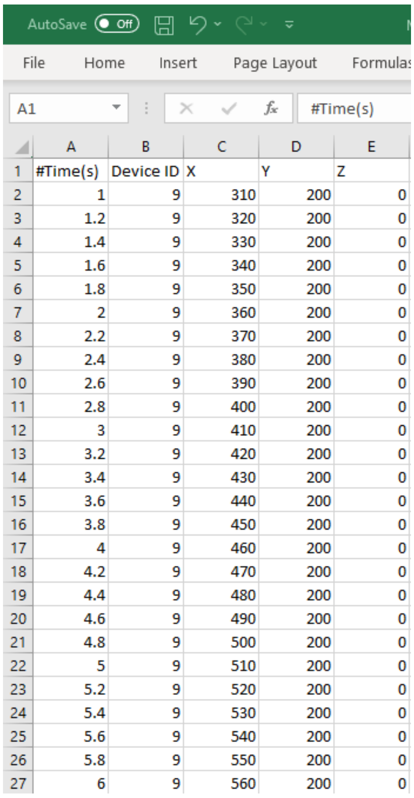
Table 2: Values set for different parameters in simulation

10. Go to UE properties. In the RAN Interface set physical layer properties in both UEs as shown below.

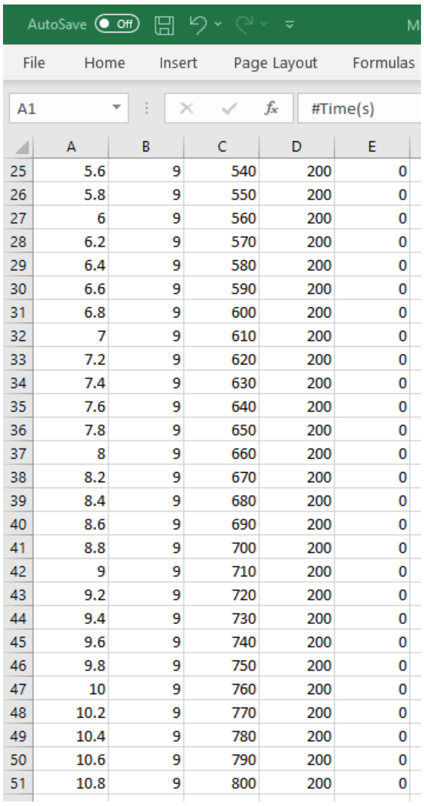
UE > Interface 5G RAN	
UE Height	1.50
Tx Power	23 dBm
Tx Antenna Count	1
Rx Antenna Count	1

Table 3: Properties set for UE

11. In the General layer, set UE X and Y coordinates as the gNB1's X and Y coordinates. That is, the initial position of UE must be the position of gNB1.
12. Set the mobility model as file-based mobility and configure the mobility that UE needs to be travel straight towards to the gNB2. So, configure the mobility file according to the distance that UE needs to travel. For example, in the above scenario, UE needs to travel 500m from gNB1 to gNB2 So, it is travelling straight towards to another gNB since it's Y coordinate is fixed. Hence, give input in the excel sheet as in Fig. 5.
13. Before clicking on Run, select the "logs" option, and check "LTENR Radio Measurements Log." Fig 7
14. Now, Run the Simulation for 12 s.



	A	B	C	D	E
1	#Time(s)	Device ID	X	Y	Z
2	1	9	310	200	0
3	1.2	9	320	200	0
4	1.4	9	330	200	0
5	1.6	9	340	200	0
6	1.8	9	350	200	0
7	2	9	360	200	0
8	2.2	9	370	200	0
9	2.4	9	380	200	0
10	2.6	9	390	200	0
11	2.8	9	400	200	0
12	3	9	410	200	0
13	3.2	9	420	200	0
14	3.4	9	430	200	0
15	3.6	9	440	200	0
16	3.8	9	450	200	0
17	4	9	460	200	0
18	4.2	9	470	200	0
19	4.4	9	480	200	0
20	4.6	9	490	200	0
21	4.8	9	500	200	0
22	5	9	510	200	0
23	5.2	9	520	200	0
24	5.4	9	530	200	0
25	5.6	9	540	200	0
26	5.8	9	550	200	0
27	6	9	560	200	0



	A	B	C	D	E
25	5.6	9	540	200	0
26	5.8	9	550	200	0
27	6	9	560	200	0
28	6.2	9	570	200	0
29	6.4	9	580	200	0
30	6.6	9	590	200	0
31	6.8	9	600	200	0
32	7	9	610	200	0
33	7.2	9	620	200	0
34	7.4	9	630	200	0
35	7.6	9	640	200	0
36	7.8	9	650	200	0
37	8	9	660	200	0
38	8.2	9	670	200	0
39	8.4	9	680	200	0
40	8.6	9	690	200	0
41	8.8	9	700	200	0
42	9	9	710	200	0
43	9.2	9	720	200	0
44	9.4	9	730	200	0
45	9.6	9	740	200	0
46	9.8	9	750	200	0
47	10	9	760	200	0
48	10.2	9	770	200	0
49	10.4	9	780	200	0
50	10.6	9	790	200	0
51	10.8	9	800	200	0

Fig 6: UE mobility file for 500m

15. After simulation, open LTENR Radio measurement log present under the Log files section in the Results Dashboard as in Fig 8

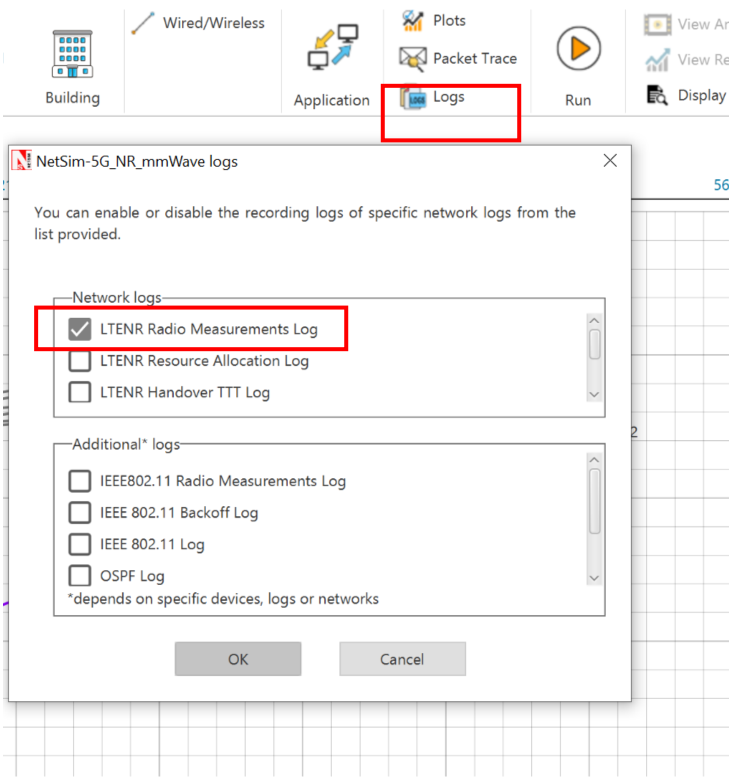


Fig 7: Enabling the Log options.

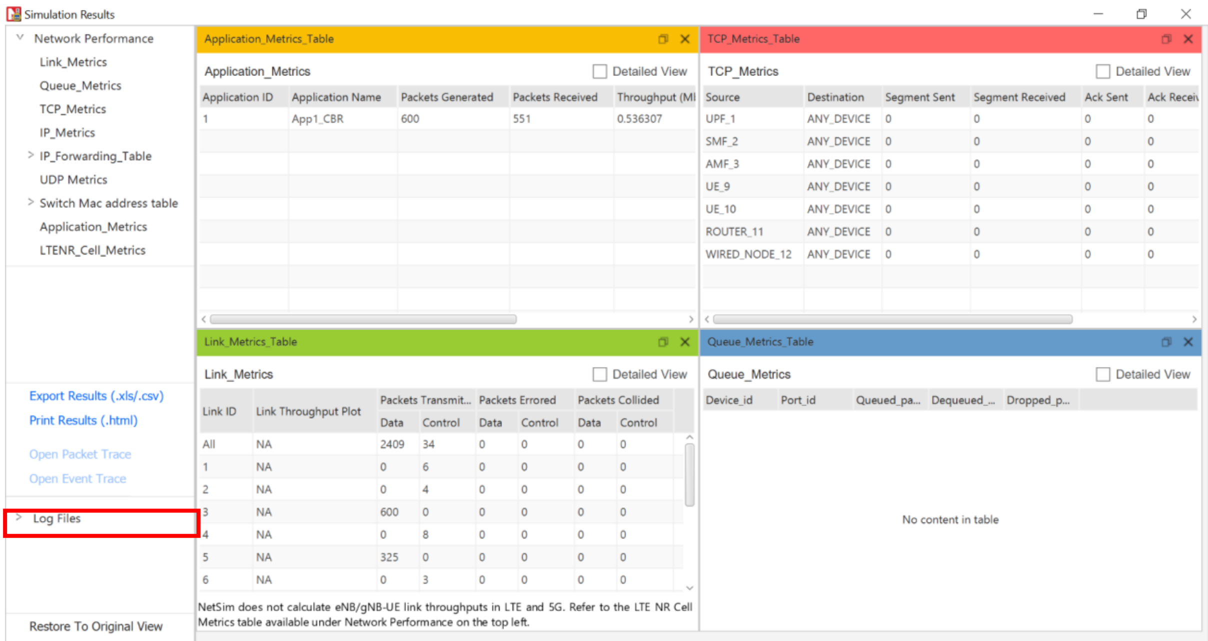


Fig 8:ISD 500m simulation result Dashboard.

16. Create a pivot table for this log file by clicking the pivot option present at the top of the ribbon under insert section as shown below.

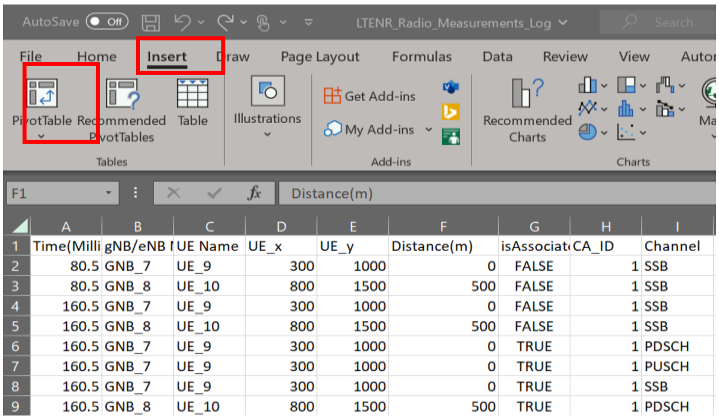


Fig 9: Inserting pivot table

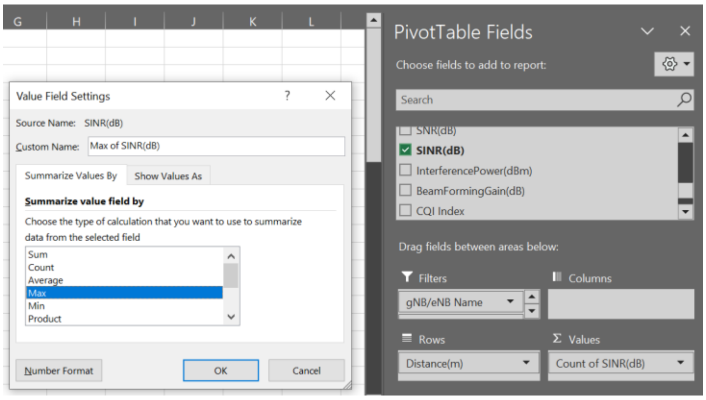


Fig 10: Creating pivot table

17. In the pivot table drop 'gNB/eNB Name', 'UE Name', 'Channel' fields under filters area, drop 'Distance' in Row area and drop 'SINR' in Value area. Set the SINR values to max by clicking on the arrow icon present at the end of the field ->value field setting->max as shown below as shown in Fig 10.

18. Now filter gNB as gNB7, UE name as UE_9, Channel as PDSCH as shown in Fig. 10.

19. Copy the values from 0 to 290 along with Row Labels and Max_SINR_dB header and paste it into another sheet. Similarly filter gNB/eNB name to GNB_8 and copy the row label value along with SINR and paste it into next to the previously created new sheet.

20. NetSim calculates the distance of a UE from its attached gNB. In the plot that we eventually wish to obtain the X axis has distance from the initial attached gNB which is gNB7. In our experiment, UE9 is initially attached to gNB7 and post-handover it gets attached to gNB8. Since gNB7 to gNB8 distance is 500m, post-handover the distance of UE9 from the initial gNB7 is $500 - d_{gNB(8)}^{UE(9)}$ i.e., $d_{gNB(7)}^{UE(9)} = 500 - d_{gNB(8)}^{UE(9)}$
    a. Copy the Row table and distance to the empty cells after filtering that gNB/eNB Name to gNB8 and UE Name to UE9 as shown in Fig 11
    b. In the adjacent cell calculate the UE_9 distance from gNB_7 as shown below as shown in Fig 12. Observe that it is initially $d_{gNB(7)}^{UE(9)}$ and post-handover it is $500 - d_{gNB(8)}^{UE(9)}$.
    c. Distance between UE9 and gNB7, $d_{gNB(7)}^{UE(9)}$, along with the SINR value and copy them into new cells
    d. Filter it from the ascending order/ smallest to largest, copy these values to the paste it below the previously created new sheet as shown in Fig 13

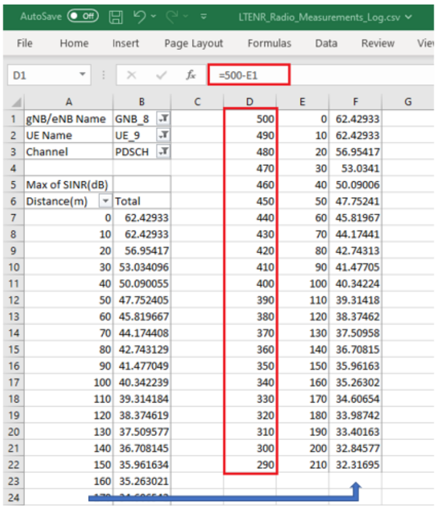


Fig 11: Copying the Distance and SINR values into new cells.

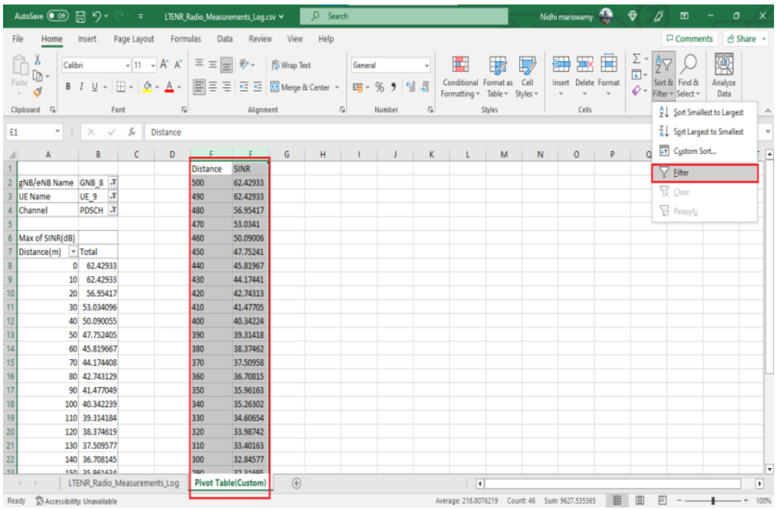


Fig 12: Inserting filter.

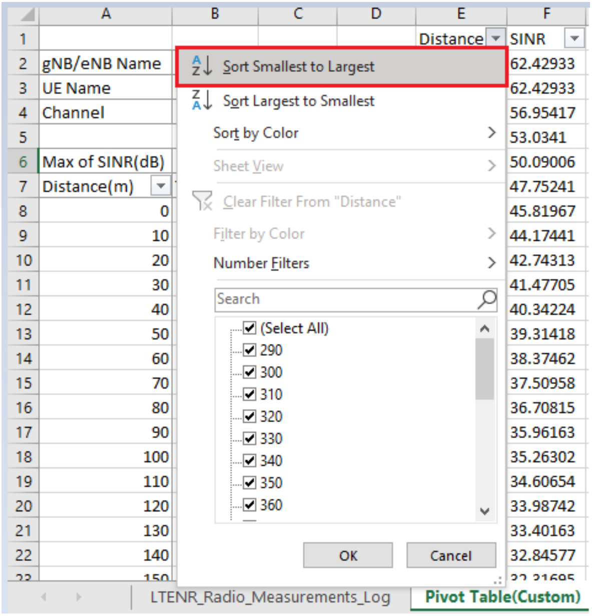


Fig 13: Sorting from smallest to largest

Results:

Distance	Max of SNR(dB)
0	62.43
10	62.43
20	56.95
30	53.03
40	50.09
50	47.75
60	45.82
70	44.17
80	42.74
90	41.48
100	40.34
110	39.31
120	38.37
130	37.51
140	36.71
150	35.96
160	35.26
170	34.61
180	33.99
190	33.40
200	32.85
210	32.32
220	31.81
230	31.33
240	30.87
250	30.43
260	30.00
270	29.59
280	29.20
290	28.82

Fig 15: Downlink SINR values for GNB_7, with ISD = 500m.

Distance	Max of SNR(dB)
290	32.32
300	32.85
310	33.40
320	33.99
330	34.61
340	35.26
350	35.96
360	36.71
370	37.51
380	38.37
390	39.31
400	40.34
410	41.48
420	42.74
430	44.17
440	45.82
450	47.75
460	50.09
470	53.03
480	56.95
490	62.43
500	62.43

Fig 14: Downlink SINR results GNB_8, with ISD = 500m

Case #2: No interference in both base stations with $\eta = 4$

gNB7 > Interface 5G RAN	
PathLoss Model	LOG_DISTANCE
PathLoss Exponent	4
Downlink Interference	No Interference
gNB 8 > Interface 5G RAN	
PathLoss Model	LOG_DISTANCE
PathLoss Exponent	4
Downlink interference	No Interference

Table 4: Properties set for Case 02.

Set the above property values and simulate the scenario for 12 sec. Tabulate the results obtained from LTENR Radio measurement log in the simulation metrics window.

Case #3: UE to Both Base stations is in $\eta = 2.5$.

gNB7 > Interface 5G RAN	
PathLoss Model	LOG_DISTANCE
PathLoss Exponent	2.5
Downlink Interference	Exact geometric model
gNB 8 > Interface 5G RAN	
PathLoss Model	LOG_DISTANCE
PathLoss Exponent	2.5
Downlink interference	Exact geometric model

Table 5: Properties set for Case 03.

Set the above property values and simulate the scenario for 12 sec. Tabulate the results obtained from LTENR Radio measurement log in the simulation metrics window.

Case #4: UE to Both Base stations with $\eta = 4$.

gNB7 > Interface 5G RAN	
PathLoss Model	LOG_DISTANCE
PathLoss Exponent	4
Downlink Interference	Exact geometric model
gNB 8 > Interface 5G RAN	
PathLoss Model	LOG_DISTANCE
PathLoss Exponent	4
Downlink interference	Exact geometric model

Table 6: Properties set for Case 04.

Set the above property values and simulate the scenario for 12 sec. Tabulate the results obtained from LTENR Radio measurement log in simulation metrics window.

Results. UE with $\eta = 2.5, and\ 4$

Distance	Case #2 DL SINR (dB)	Case #3 DL SINR (dB)	Case #4 DL SINR (dB)
0	45.66	39.50	45.58
10	45.66	39.28	45.58
20	36.90	33.59	36.81
30	30.63	29.44	30.53
40	25.92	26.26	25.81
50	22.18	23.69	22.06
60	19.08	21.51	18.96
70	16.45	19.62	16.31
80	14.16	17.93	14.01
90	12.13	16.40	11.97
100	10.32	15.00	10.14
110	8.67	13.70	8.47
120	7.17	12.48	6.95
130	5.79	11.33	5.54
140	4.50	10.23	4.23
150	3.31	9.18	3.01
160	2.19	8.16	1.85
170	1.14	7.18	0.76
180	0.15	6.23	-0.28
190	-0.79	5.30	-1.27
200	-1.68	4.39	-2.22
210	-2.52	3.49	-3.14
220	-3.33	2.61	-4.04
230	-4.10	1.73	-4.91
240	-4.84	0.86	-5.77
250	-5.55	0.00	-6.61
260	-6.23	-0.87	-7.46
270	-6.88	-1.74	-8.31
280	-7.51	-2.62	-9.17
280	-3.33	-2.62	-4.04
290	-2.52	-3.50	-3.14
290	-2.52	3.49	-3.14
300	-1.68	4.39	-2.22
310	-0.79	5.30	-1.27
320	0.15	6.23	-0.28
330	1.14	7.18	0.76
340	2.19	8.16	1.85
350	3.31	9.18	3.01
360	4.50	10.23	4.23
370	5.79	11.33	5.54
380	7.17	12.48	6.95
390	8.67	13.70	8.47
400	10.32	15.00	10.14
410	12.13	16.40	11.97
420	14.16	17.93	14.01
430	16.45	19.62	16.31
440	19.08	21.51	18.96
450	22.18	23.69	22.06
460	25.92	26.26	25.81
470	30.63	29.44	30.53
480	36.90	33.59	36.81
490	45.66	39.28	45.58
500	45.66	39.50	45.58

Table 7: Results for SINR vs. distance for ISD-500m downlink.

The red marks indicate the points of handover.

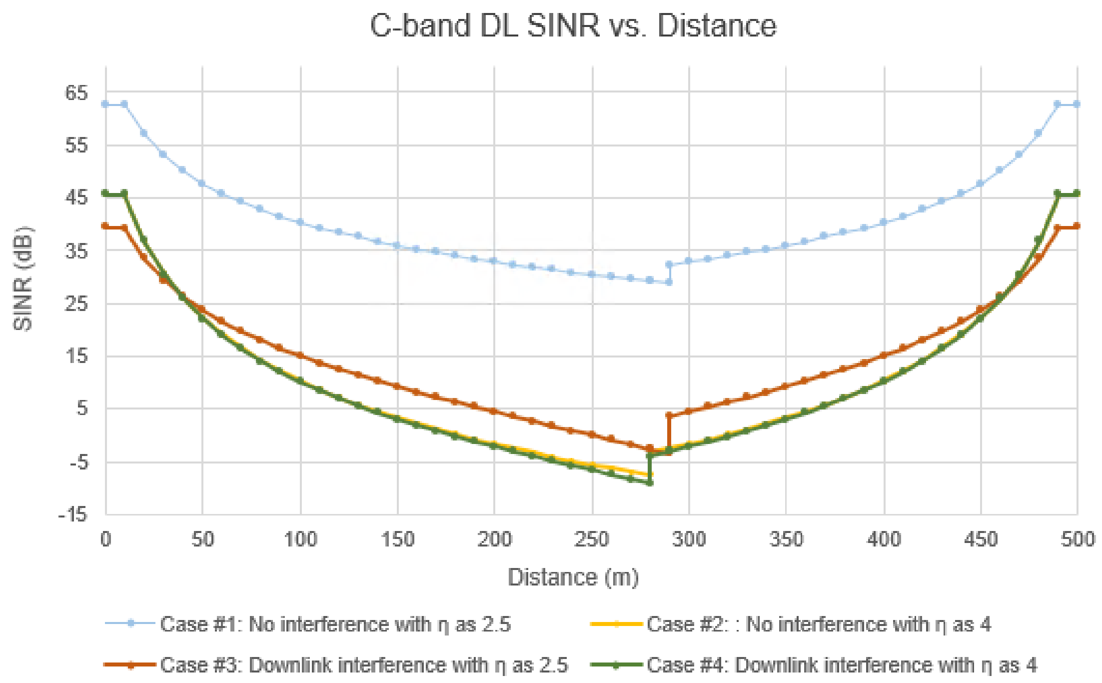


Fig 16: Downlink SINR vs. distance plot for C-band for different network configurations.

Discussion

Initially (in case 1), the UE is attached to BS_1. In the scenario, the UE moves in a straight line towards BS_2 and at 290 m it is handed over to BS_2. Till 290 m the "desired" signal is from BS_1 while the "interfering" signal is from BS_2. Post-handover there is a reversal; the desired signal is from BS_2 while the interfering signal is from BS_1.

Signals from BS_1 and from BS_2 to the UE undergo pathloss. If the transmit powers at both BSs are P_t then the $SINR$ works out to be

$$SINR = \frac{P_t \times PL(d)}{N_0 \times W + P_t \times PL(d_{ISD} - d)}$$

Where $PL(d)$ is the pathloss loss (per the 3GPP pathloss models) at a distance of d. Since the distance between the two BSs is equal to d_{ISD}, the inter site distance, the UE is at a distance of $(d_{ISD} - d)$ from the interfering BS, and hence the $PL(d_{ISD} - d)$ term in the denominator. When there is a line-of-sight (LOS) condition with a gNB, the path loss is lower, modelled here by setting the path loss exponent as 2.5. When there is a non-line-of-sight (NLOS) condition with a gNB, the path loss is higher, modelled here by setting the path loss exponent as 4.

With this background, let us look Fig 16

- In all cases, we see a constant SINR till 10m because the pathloss equations defined in the standard take effect only from 10m.
- SINR. vs distance is plotted for four cases
    - Case #1: UE is in LOS with both BSs, interference is turned off
    - Case #2: UE is in NLOS with both BSs, interference is turned off
    - Case #3: UE is in LOS with both BSs, with interference turned on
    - Case #4: UE is in NLOS with both BSs, with interference turned on

Note: Here, we use the terms LOS for $\boldsymbol{\eta = 2.5}$, and NLOS for $\boldsymbol{\eta = 4}$, for simplicity.

- In case 1 and case 2, the term I in $SINR = \frac{P_r}{N_0 W + I}$ is set to zero. Practically, this means that the two BSs operate in non-overlapping frequency bands. Therefore, $SINR = SNR = \frac{P_r}{N_0 W}$. We see the SNR dropping as the UE moves away from BS_1. At 280/290m, it gets handed over to BS_2, and we see the SNR increasing as the UE moves closer to BS_2. Why is there a "jump" at the handover point? This is because the standards specify that handover should occur only when target-gNB's SINR is offset (3 dB) higher than serving-gNB's SINR. This condition is satisfied at 280m. You are encouraged to think about the question: Why does the standard specify such an offset?
- Next, we observe that the NLOS curve (purple) is lower than the LOS curve (blue). This is because NLOS pathloss is higher than the LOS pathloss.
- In Cases 3, and 4, the observations are similar to above, but they are lower than their respective counterparts in cases 1 and 2, due to additional interferences which degrade the SINR further. Further, we notice that the two curves of cases 2 and 4 are very close to each other. Why?
    - Open the log files for these cases and observe the following: The pathloss is more pronounced in these cases, and the interference also decays faster than the case (3) case. Hence, the effect of interference is not very pronounced, leading to almost similar performance.
    - **Optional Exercise**: Check whether the gap between the two curves increases by increasing gNB transmit powers (i.e., increasing the interference power).

B. Understanding the points of handoff

For the sake of exposition, we investigate the point of hand-off for case #1 and case #2 where the interferences are assumed to be absent from the base-stations. This therefore represents a noise limited regime, or a scenario where the two BSs use non-overlapping frequency bands. In such a scenario, as the UE moves from BS_1 towards BS_2, the SNR from BS_1 decreases, while the SNR from BS_2 increases. The point where the SNR from BS_2 is 3 dB higher than that from BS_1 determines the point of handoff. But we observe that between the cases with path loss exponents of 2.5 and 4, the points of handovers are different! Why? Read the discussion below.

Further Discussion:

For the sake of generality, we discuss the effect of path loss exponent on handover in a general setting independent of the values obtained in the experiment. Consider the scenario:

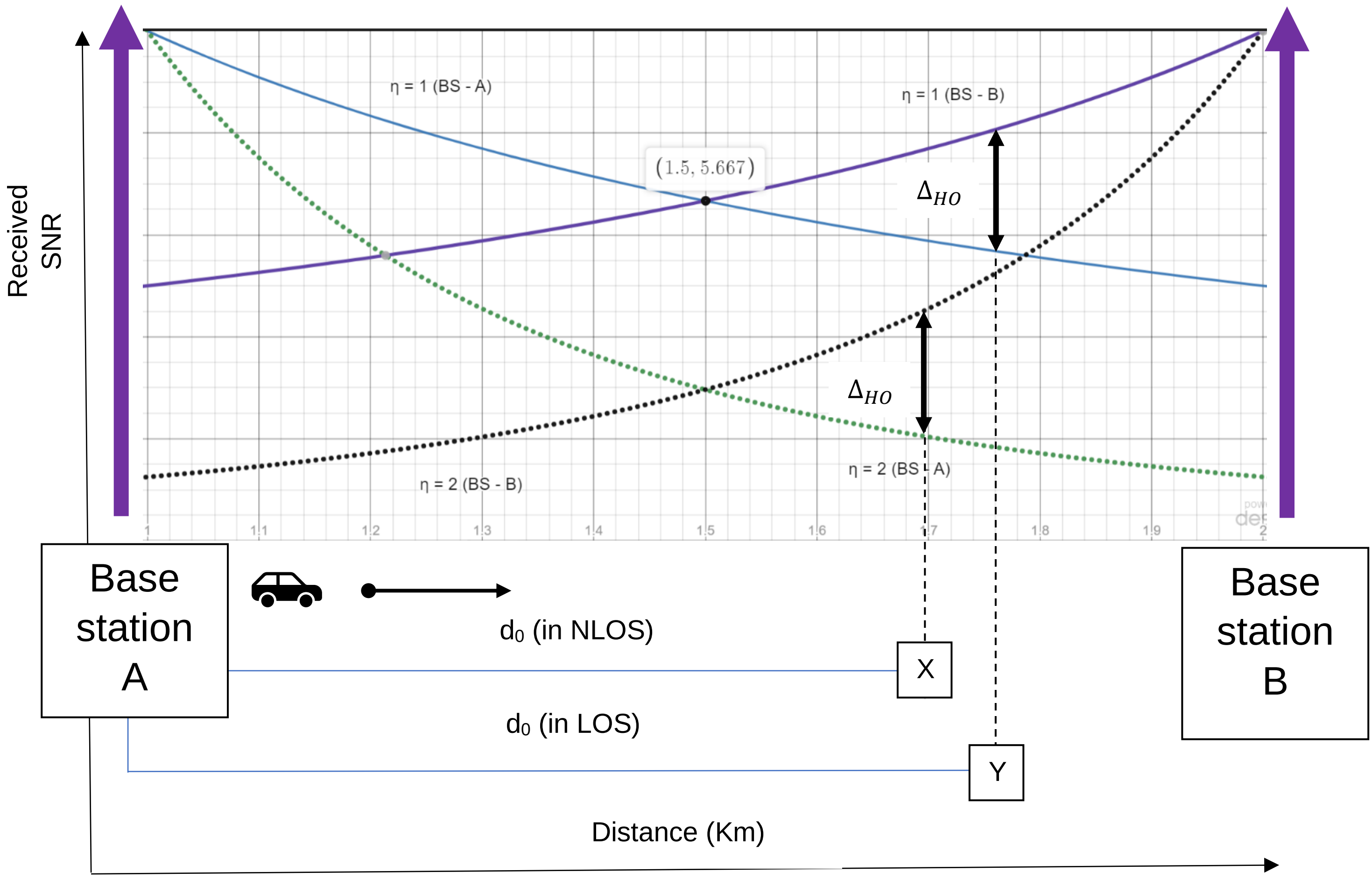


Fig 17: Illustration of different handover points in LOS/NLOS cases

Case A: Noise limited scenario

Let a UE move from base station A towards base station B with inter site distance = 1 km as shown in Fig 17. Consider for the moment that we are in a noise-limited regime, where the interferences are assumed to be absent from the base-stations. In such a scenario, as the UE moves from BS A towards BS B, the SNR seen by the UE from BS A decreases, while the SNR seen from BS B increases. For example, let the path loss exponent be set to 1 (η=1), then solid blue curve represents the received SNR as a function of distance seen from BS A, while solid purple curve represents the received SNR as a function of distance seen from BS B. Further, assume that Δ_{HO} is the "handoff threshold" or "handover margin", i.e., the required SNR difference between the base stations in order to perform a handoff from BS A to BS B. Let the distance at this point be d_0. This point is indicated by the point Y in the above plot.

However, when the path loss exponent increases to 2, i.e., η=2, the received SNR from both the BSs changes and the corresponding curves are shown in the above figure using dashed lines. Clearly, due to the differing slopes in the SNR curves at different values of η, **the point at which the handoff occurs is different** (in fact it occurs earlier than the former case) and this point is indicated by X.

Conclusion: The point of handoff is different for environments with different pathloss exponents for a given handoff threshold.

Remarks: Observe from the figure that, as we increase the path loss from 1 to 2, the point of handoff occurs at d = 1.7 Km and d = 1.76 Km, respectively. This difference is more pronounced when the pathloss difference increases.

Case B: Interference limited scenario.

In this case, a similar plot (like above) can be used for handoff analysis, except that y-axis will now have the SINR instead of SNR. It is an exercise for the reader to understand and explain the impact of interference on the handover points in the LOS/NLOS cases.

YOUR EXERCISES

Let the last two digits of your trainee ID be xx. Then set the inter-gNB distance to (500 + ceil(xx/2)) meters in the GUI.

1. **Replicate the above experiment (reproduce table 7, and figure 10,11 and 12, only) for all the four cases. Set the mobility profile accordingly.**
2. **Repeat question – 1 using a different band (for example n5 or low band, 850 MHz). Justify the changes in your results compared to Q1 (if any.)**
3. **In the above two exercises, no fluctuations in the channel were enabled. Now, repeat question (1) by adding shadowing in the simulations and observe possible ping-pong handovers. Interpret your observations with suitable justifications.**

References

[1] M. Haenggi and R. K. Ganti, "Interference in Large Wireless Networks," 2009.

Note:

Go to the gNB properties. Then under 5G RAN settings: select following:

1. **Duplex Mode: FDD**
2. **CA Type: SINGLE_BAND**

CA Con Fig 18: Downlink SINR results GNB_8, with ISD = 500m

3. **uration: n5**